BENTHIC MACROINVERTEBRATE COMMUNITIES AND WATER QUALITY OF HEADWATER STREAMS OF THE OAK RIDGES MORAINE: REFERENCE CONDITIONS

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BENTHIC MACROINVERTEBRATE COMMUNITIES AND WATER QUALITY OF HEADWATER STREAMS OF THE OAK RIDGES MORAINE: REFERENCE CONDITIONS

Report prepared by:

Stephen H. Maude
and
Joanne Di Maio

Central Region
Ontario Ministry of Environment and Energy

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SUMMARY

The Oak Ridges Moraine is a prominent physiographic feature of southern Ontario and functions as the source area for many headwater streams. It has been the focus of increased attention recently because of concern about its long-term protection in the face of rapid urban sprawl in the Greater Toronto Area. The concepts of ecoregions and regional reference sites, now commonly applied in water resource management, provide a useful framework for consideration of headwater streams of the Oak Ridges Moraine. In 1992, we undertook a water quality survey of twenty-eight sites from relatively undisturbed headwater streams of the Oak Ridges Moraine. The survey comprised the collection of physical, chemical, and biological data, with emphasis on rapid bioassessment of benthic macroinvertebrate communities. Typically, the sites sampled were small, cold, well-oxygenated, spring-fed, headwater streams that supported diverse assemblages of benthic macroinvertebrates, including a number of sensitive taxa. There was considerable variability in water chemistry across sites, however, at most sites sampled, water quality was much better than the water quality standards normally applied to surface waters. In recognition of the need for standards specific to the headwaters of the Moraine, we used data from this survey to derive a set of proposed reference values for important chemical and biological indicator parameters. The approach of Novak and Bode (1992) was also used to develop a preliminary Oak Ridges Moraine model community based on the composition of the benthic macroinvertebrate communities from the twenty-eight reference sites. Further work is required to refine this model and to define categories of impact. The proposed reference values and the model community should prove useful for evaluating observed stream conditions and impact predictions associated with land development proposals. We recommend that management strategies explicitly recognize the sensitivity, individuality, and stability of the headwater streams of the Oak Ridges Moraine.

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1.0 INTRODUCTION

Ecoregions are recognized as providing a logical spatial framework for environmental management (Omernik 1995, Omernik and Griffith 1991). Generally, ecoregions are defined as geographical regions that are relatively homogeneous with respect to ecological systems involving interrelationships among organisms and their environment (Crowley 1967, Omernik 1987). However, the scale at which ecoregions are defined and the exact means of delineating them can vary. Applications involving ecoregions are premised on the idea that biological communities within defined ecoregions should be more similar to one another than communities from other regions (Cairns and Pratt 1993). By sampling relatively undisturbed reference sites, one should be able to define typical reference conditions within an ecoregion. The utility of documenting regional reference conditions is becoming increasingly recognized in water resource management and examples exist of the successful use of regional reference sites for rivers and lakes in a number of jurisdictions in the United States (Gallant *et al.* 1989, Hughes *et al.* 1994, Whittier *et al.* 1988). In aquatic ecoregions, regional reference sites are useful for estimating ranges of attainable ecological condition, for evaluating temporal and spatial changes in ecological integrity, for setting targets for remedial work, and for developing biological criteria for watercourses (Hughes 1995, Hughes *et al.* 1986). The use of regional reference sites in impact prediction or assessment obviates some of the problems of natural variability inherent to site-specific upstream-downstream or before-after evaluations (Gerritsen 1995).

The Oak Ridges Moraine is one of the most distinctive physiographic features of southern Ontario. It is a prominent ridge, created by glacial action, that extends from the Niagara Escarpment in the west to the Trent River in the east and forms the divide between streams flowing south to Lake Ontario and streams flowing north to Georgian Bay, Lake Simcoe, and the Trent-Severn Waterway. It is regarded as the source area for many major drainage basins, including the Humber, Rouge, Duffin, Holland, Pefferlaw, and Ganaraska and features a large concentration of headwater streams (Chapman and Putnam 1984). Virtually the entire Oak Ridges Moraine is contained within the Ministry of Environment and Energy's (MOEE) Central Region.

The importance and sensitivity of the Oak Ridges Moraine have been stressed in recent reports (Kanter 1990; RCFTW 1990). The latter report contained the following recommendation:

> *The Province should take immediate steps to preserve the ecological, scenic, and recreational significance of the Oak Ridges Moraine, and to ensure that future land use in the moraine does not result in cumulative impairment of the ecological quality of downstream rivers or the waterfront.*

The Royal Commission on the Future of the Toronto Waterfront went on to recommend that the Province declare a Provincial Interest in the Moraine. On July 26, 1990, the Province made an Expression of Provincial Interest in the Oak Ridges Moraine of the Greater Toronto Area and also expressed the intent to undertake a planning study.

Subsequently, the Ministries of Natural Resources, Municipal Affairs, and Environment prepared "Implementation Guidelines" to provide assistance regarding the implementation of the expression of Provincial interest (MNR *et al.* 1991). This document defines principles, evaluation criteria, and agency roles pertaining to the review of development activities on the Oak Ridges Moraine. The MOEE is specifically identified as being responsible for commenting on matters related to water quality. For watercourses and lakes of the Moraine, the following principle applies:

> *Changes to the natural quality and hydrological characteristics of watercourses and lakes including baseflow, water quality, temperature, storage levels or capacities are to be minimized and no development shall be permitted that will result in an unacceptable impact.*

Surface water reviewers of the MOEE's Central Region are responsible for providing review comments on development proposals relative to the above principle.

The major difficulty faced by reviewers is the virtual absence of even basic information pertaining to the water quality and ecology of the small watercourses of the Oak Ridges Moraine. This problem is not unique to the Moraine. Williams (1983) encouraged a national survey of freshwater springs, stating that:

> *Basic information is woefully lacking on the flora, fauna and environmental characteristics of these habitats...*

The "Implementation Guidelines" for the Oak Ridges Moraine specify that proponents of development proposals must provide information to assist reviewers. However, it is difficult to assess such site-specific data outside the context of a more comprehensive ecoregion database. In addition, it is recognized that the MOEE reviewers' primary reference tool, the "Blue Book" (MOEE 1994a), provides little guidance for dealing with the subtle and incremental impacts typically associated with land use changes in the Oak Ridges Moraine. There is also the suspicion that the water quality objectives in the "Blue Book", which are essentially chemical surrogates of single-species biological criteria, may not adequately protect the sensitive aquatic communities of these headwater areas.

In light of the above, the collection of water quality and biological information for small watercourses of the Oak Ridges Moraine is of considerable importance. The primary objective of this study was to undertake an extensive field sampling program to characterize the biology, water chemistry, and physical habitat of relatively undisturbed watercourses of the Oak Ridges Moraine.

It is envisaged that, by providing an integrated assessment of reference conditions for headwater streams of the Moraine, this report will serve as a useful reference for surface water reviewers. It is also hoped that it may prove helpful in better understanding this ecoregion and in formulating a strategy for the long-term protection and management of the Oak Ridges Moraine.

2.0 METHODS

2.1 Study Area

The study area comprised that portion of the Oak Ridges Moraine within the Greater Toronto Area; this included the Regional Municipalities of Peel, York, and Durham. Table 1 lists the headwaters found on the Oak Ridges Moraine within the Greater Toronto Area.

2.2 Selection of Sampling Sites

Preference in sampling site selection was given to first- or second-order streams relatively undisturbed by development that had well-defined riffle areas. Candidate sites within the Oak Ridges Moraine were identified initially using 1:50 000 topographic maps. Field reconnaissance was then undertaken to ensure that the sampling sites met the above criteria. Table 2 lists the headwaters sampled, the locations of these sites, and the sampling dates; sampling site locations are also shown on Figure 1. Elevation, distance from the stream source to the sampling point, and stream gradient were determined for each sampling site from the 1:50 000 topographic maps.

2.3 Field Methods

Various biotic and abiotic factors were measured at each site including stream discharge, dissolved oxygen, temperature, and land use.

Water and benthic samples were obtained at each site. Three replicate water samples were taken from mid-stream. Samples were stored on ice and delivered to the MOEE's Rexdale laboratory, usually within 24 hours of sampling and analyzed there using standard MOEE methods (MOE 1983). Two benthic samples measuring approximately 1 m^2 were taken in a riffle area using the kick sampling method; rocks and sediment on the bottom of the stream were disturbed by foot causing dislodged organisms to drift downstream into a D-frame net. Sampling continued for approximately five minutes or until the entire sampling area had been covered. Each sample was placed into a white plastic tray, examined, and the macroinvertebrates were collected and preserved in 70% ethanol. The sampling procedure emphasized the collection of a variety of organisms and at least 100 individuals were collected at each site. To limit bias, two investigators sampled independently.

A discharge metering section was selected at a reach of the stream where the bed and banks were relatively straight and uniform. A tape measure was strung across the stream to measure its total width. Observation verticals were established at 1/4, 1/2, and 3/4 of the stream width, except where stream widths measured 75 cm or less, in which case only the centre point was used as an observation vertical. Stream depth was measured at each observation vertical using a metre stick. A Marsh-McBirney Model 201D portable water current meter was used to measure the stream velocity at a point located 0.4 of the total depth up from the stream bottom. This is the depth at which the mean velocity occurs in shallow streams (Terzi 1981). Discharge was calculated using the mean section method (Terzi 1981), assuming the stream edges to have depths and velocities of zero.

Air and water temperatures were taken at approximately the same time of day and always between 1130 hr and 1530 hr. Air temperature was read from a thermometer that had been hanging in the shade. The water temperature was recorded with a Yellow Springs Instrument (YSI) model 57 oxygen meter in a pool area of the stream.

Dissolved oxygen was measured in a pool area using a YSI model 57 oxygen meter that was calibrated daily in a calibration chamber according to the air calibration method (YSI 1983).

2.4 Sample Sorting, Identification, and Community Metrics

For each site, the two benthic macroinvertebrate samples were combined, sorted, and individuals identified to the lowest taxonomic level that could be readily determined: to species for hydropsychids; to genera for Odonata, Coleoptera, Megaloptera, Hemiptera, Plecoptera, Ephemeroptera, remaining Trichoptera, most Diptera, Amphipoda, Isopoda, and Decapoda; to subfamily or tribe for Chironomidae; to family for Simuliidae; to class for Oligochaeta, Gastropoda, Turbellaria, Hirudinea, and Bivalvia; to order for Diplopoda; and to subcohort for Hydrachnidia. Published keys used to identify the organisms included Peckarsky *et al.* (1990), Pennak (1978), and Merritt and Cummins (1978); unpublished keys (R.J. Mackay) were used to identify hydropsychids and chironomids.

There are a number of metrics or indices that can be calculated to describe the benthic macroinvertebrate communities sampled using rapid bioassessment techniques. In general, the various metrics can provide summary measures of richness, abundance, diversity, tolerance to organic pollution, or functional feeding groups, but not all metrics are equally useful at discriminating between impacted and non-impacted conditions (see Resh and Jackson (1993) for a helpful review of metrics). In this study, we used the benthic macroinvertebrate data to

calculate the following metrics for each site: total abundance (total number of individuals in the sample), total taxa richness (total number of distinct taxa), percent contribution of major insect orders to total abundance, EPT taxa richness (the number of distinct taxa within the orders Ephemeroptera, Plecoptera, and Trichoptera), and Hilsenhoff's Biotic Index. In calculating total and EPT taxa richness, we counted the *Hydropsyche* species as one taxon to be consistent with the predominately generic-level taxonomy used for other groups.

Hilsenhoff's Biotic Index is a numerical scale developed for use in shallow riffles to evaluate the relative degree of organic or nutrient pollution; biotic index scores range from 0-10, with 0 being the least polluted and 10 being the most polluted. Scores are calculated by multiplying the number of individuals collected from a given taxon by the pollution tolerance value (0-10) for that taxon, summing these products for all taxa, and dividing by the total number of individuals collected (Hilsenhoff 1982, Hilsenhoff 1987). Hilsenhoff's biotic index is widely used, but comparison of index scores across studies must be approached cautiously because index scores are affected by the taxonomic levels used and the season of sample collection and these often vary from study to study. We used the pollution tolerance scores suggested by Bode (1988) and Hilsenhoff (1987, 1988) according to the most detailed level of taxonomy we had available and did not adjust the biotic index scores for season. Hemiptera and Diplopoda were not included in the calculation of the biotic index because pollution tolerance values for these taxa were not available.

3.0 RESULTS

From May 20 to August 11, 1992, chemical and benthic samples were collected from thirty sites located across the Oak Ridges Moraine (Table 2, Figure 1). Many sites were identified in the site selection process but some were later rejected because they did not meet the criteria of an acceptable site. Sampling evenly across the moraine was attempted, however, in some locations, especially near rapidly urbanizing areas, acceptable sites could not be found. After sampling, it was discovered that there were significant areas of developed land upstream of site 7 and site 10. Because the two sites had potentially been impacted by these developments, these sites were excluded from the data analysis which follows. However, the original site numbering has been retained.

3.1 Water Chemistry

The sites sampled were typically small, cold, well-oxygenated, spring-fed, headwater streams (Table 3). Most of the streams had water temperatures below 20°C, the coldest being a tributary of the Ganaraska River (site 29) where the water temperature was 9°C at the time of sampling. Observed dissolved oxygen levels ranged from 73% saturation to 113% saturation, well above the MOEE's Provincial Water Quality Objective for cold-water biota (MOEE 1994a). Most sites had dissolved oxygen levels close to 100% saturation. Measured stream discharge ranged from 1 L/s to 129 L/s.

Although all of the sites can be characterized as having hard, alkaline water with high concentrations of dissolved salts, there nevertheless were fairly wide ranges in measured water chemistry across sites (Table 3). Site mean conductivities ranged from 262 μmho/cm (site 25) to 552 μmho/cm (site 1). Site 25 also had the lowest means for hardness and alkalinity at 136 mg/L and 125 mg/L, respectively. Maxima for mean hardness (263 mg/L) and mean alkalinity (236 mg/L) occurred at site 16. Site mean pH ranged from 8.1 to 8.4, which is within the acceptable limits for the protection of aquatic life (MOEE 1994a).

Ionic balances agreed to within 8% or less when calculated using the equivalent concentrations of the cations calcium, magnesium, sodium, and potassium and the anions bicarbonate (estimated from alkalinity), sulphate, and chloride.

Calcium was the dominant cation, accounting for between 61% and 78% of the total cations in solution. Site mean calcium concentrations varied from 39 mg/L to 78 mg/L. Magnesium was of secondary importance, representing between 16% to 31% of the total cations, with site mean

concentrations that ranged from 8 mg/L to 19 mg/L. Sodium was a minor component of the total cations, accounting for between 2% and 19% of the total. Only at sites 1, 22, 24, and 28 did sodium represent greater than 10% of the total cations. Site mean sodium concentrations ranged from 2 mg/L to 25 mg/L. Potassium was a minor cation, representing 1% or less of the total cations. Site mean concentrations of potassium ranged from 0.46 mg/L to 1.3 mg/L.

Although not measured directly, the dominant anion was likely bicarbonate, as estimated from measured alkalinity. Bicarbonate accounted for between 70% and 91% of the total anions in solution. Site mean alkalinities (as equivalent bicarbonate) ranged from 152 mg/L to 288 mg/L. Sulphate was a relatively minor anion, contributing between 6% and 14% of the total anions. Site mean concentrations of sulphate ranged from 12 mg/L to 34 mg/L. Chloride constituted between 1% and 23% of the total anions and was important at only a small number of sites. At seven sites, sites 1, 2, 9, 14, 22, 24, and 28, chloride accounted for greater than 10% of the total anions. Except for site 14, all of these had sodium as a prominent cation, suggesting that these sites may have been influenced by road salt. Site mean chloride concentrations ranged from 1.5 mg/L to 48 mg/L.

Site mean total phosphorus concentrations ranged from 0.002 mg/L to 0.075 mg/L. At sites 18, 21, and 27 mean total phosphorus concentrations exceeded the MOEE's Interim Provincial Water Quality Objective of 0.03 mg/L for the elimination of excessive plant growth in rivers and streams (MOE 1994a). With the exception of sites 16, 21, and 27, filtered reactive phosphates were found only in minute concentrations.

Site mean concentrations of total Kjeldahl nitrogen ranged from 0.04 mg/L to 0.52 mg/L. Sixteen sites had mean ammonia nitrogen concentrations less than the detection limit of 0.002 mg/L; concentrations ranged up to 0.065 mg/L. All samples collected had unionized ammonia concentrations well below the Provincial Water Quality Objective of 0.02 mg/L established for the protection of aquatic life (MOE 1994a). There was a wide range of nitrate concentrations, with site means between 0.01 mg/L and 4.5 mg/L. Eight sites had mean nitrate concentrations greater than 1 mg/L. Site mean nitrite concentrations ranged from trace amounts of 0.001 mg/L to 0.037 mg/L; all of the measured concentrations were below 0.06 mg/L, the recommended guideline for the protection of aquatic life (CCREM 1987).

3.2 Benthic Macroinvertebrates

Benthic macroinvertebrates collected comprised 93 different taxa, with total taxa richnesses ranging from 11 at site 4 to 30 at site 25 (Table 4). Total abundances ranged from 104 individuals (site 27) to 634 individuals (site 8). Non-insect taxa (Oligochaeta, Amphipoda, Gastropoda, Hydrachnidia, Diplopoda, Turbellaria, Hirudinea, Isopoda, Decapoda, and Bivalvia) and Anisoptera, Zygoptera, Megaloptera, and Hemiptera did not contribute greatly to the total number of individuals collected. Individuals of these taxa made up only 8% of all the organisms collected. The main insect orders, namely, Ephemeroptera, Plecoptera, Trichoptera, Coleoptera and Diptera comprised between 81% and 100% (mean = 92%) of total abundances at the sites.

Table 5 summarizes the relative abundance patterns for the major insect orders. Ephemeroptera were absent from sites 1 and 14 and only one individual was found at each of sites 29 and 30. In contrast, at sites 3, 4, and 15 Ephemeroptera were dominant (>50%). Plecoptera were not found at sites 8, 19, 22, 24, or 30 and occurred in low numbers at most other sites except sites 1, 2, and 29 where they represented at least 25% of the total number of individuals collected. Coleoptera were absent from sites 12, 21, and 27 and only one individual was collected at each of sites 6, 28, and 29. At sites 8, 9, 19, 22, and 24 Coleoptera were abundant (>25% ≤50%). Both Trichoptera and Diptera were present at all sites. Trichoptera were rare (<10%) at site 4 and were never dominant, whereas Diptera were rare at sites 3, 4, 6, and 15 but they were dominant at sites 12, 14, and 20. Overall, the most abundant taxon was Diptera, representing 30% of the total individuals collected.

Taxa that were both relatively common and abundant included the stonefly *Amphinemura*, the mayflies *Baetis* and *Paraleptophlebia*, the caddisflies *Hydropsyche, Cheumatopsyche, Rhyacophila, Neophylax, Dolophilodes* and *Lepidostoma*, the riffle beetles, *Optioservus* and *Stenelmis*, and the dipteran families Chironomidae, Simuliidae, and Tipulidae.

Sixteen taxa were unique, each being found at only one site. These were found in very low abundances, with the exception of the caddisfly *Helicopsyche* at site 8 where 75 individuals were collected. *Helicopsyche* is an easily overlooked caddisfly that constructs a helical case of sand grains or tiny stones resembling a snail shell which is attached to rocks.

Most of the philopotamids were collected after mid-June and the simuliids were collected more often beginning in early to mid-June, peaking in July and declining in numbers towards mid-August. This may suggest that there is a seasonal influence to these collections due to the life cycle of the insects.

Values of EPT richness (defined here as the total number of **genera** of mayflies, stoneflies, and caddisflies) ranged across sites from 4 to 14. Hilsenhoff's biotic index scores ranged from 1.33 to 5.26, spanning Hilsenhoff's (1987) excellent (11 sites), very good (12 sites), and good (5 sites) water quality categories, indicative of, at worst, some slight organic pollution. We suspect that the biotic index scores from some of our sites may actually be inflated due to the lack of detailed taxonomy and consequent use of more-general pollution tolerance values for simuliids, chironomids, and oligochaetes, and also perhaps due to a seasonal influence.

4.0 DISCUSSION

Recently there has been a renewed interest in cost-effective qualitative approaches to water quality assessment as opposed to more expensive quantitative studies. This is particularly true in the United States, where rapid bioassessment methods involving multiple metrics (indices) are now commonly used (Plafkin *et al.* 1989, Resh and Jackson 1993). One of the difficulties of using these qualitative approaches to assess similarity to reference conditions is in choosing appropriate criteria and thresholds to distinguish between acceptable and unacceptable environmental conditions.

Two approaches are typically used. One approach, explored by Di Maio (1993) using data from this study, involves the use of multivariate exploratory statistics to construct predictive models (Norris 1995, Wright *et al.* 1984).

The second approach involves the use of what are essentially arbitrary thresholds to discriminate various levels of impairment with reference to an unimpaired reference condition. Typically, thresholds based on the 25th or 75th percentiles of the reference parameters have been used; the 25th percentile is used for parameters such as EPT richness for which higher numeric values correspond to better environmental quality, whereas the 75th percentile is used for parameters where higher values imply lower quality, for instance, total phosphorus concentration (Gerritsen 1995, Hannaford and Resh 1995). In both cases, 75% of the reference samples will, by definition, exhibit better quality than the reference threshold with respect to the parameter being considered. These threshold levels are consistent with those advocated by the MOEE (1994b) for establishing background water quality conditions. We used the 25th or 75th percentiles of site mean concentrations (Table 3) and biological metrics (Table 4) to derive a set of proposed reference values for important indicator parameters (Table 6).

Environmental impact predictions of land use change normally emphasize prediction of post-development in-stream chemical concentrations based on mass-balance equations, followed by comparison of these predicted values to pre-development conditions or applicable water quality standards. Although protection of the biological community is the ultimate aim of most water quality management programs, direct predictions of potential biological impact are difficult, subjective, and, consequently, rarely used. In practice, the protection of the biological community is presumed on the basis of maintaining appropriate water chemistry conditions.

In light of this and the need for definition of standards applicable to headwater streams of the Oak Ridges Moraine, we propose that the chemical concentrations in Table 6 be used as provisional impairment thresholds against which water chemistry data or predictions be assessed.

Di Maio (1993) found that water temperature, total phosphorus, and chloride were important variables in separating the Oak Ridges Moraine sites. Given that land development often causes increases in the levels of these parameters and that even subtle increases may be related to changes in the biological communities, it is prudent to set conservative water chemistry targets for impact prediction in these headwater streams. Recognizing the difficulty of predicting biological condition directly, we propose that the reference values for the biological metrics be used as screening-level benchmarks to evaluate observed stream quality.

In addition to the metrics in Table 6, we also developed a preliminary model community based on the composition of the macroinvertebrate communities of the Oak Ridges Moraine reference sites. Novak and Bode (1992) employed this approach in their work on shallow freshwater streams in New York State. An ideal, model community is described based on the mean percentage contribution of seven organism groups to total abundance. The model Oak Ridges Moraine community based on our study is shown in Figure 2, compared with the New York State model for pristine streams.

There is greater internal variability in the Oak Ridges Moraine model than in Novak and Bode's (1992) model and also some differences between the two models. These differences may reflect variations due to region, sampling techniques, samplers (see Hannaford and Resh 1995), or may reflect the difficulty of locating truly pristine reference sites (Hughes 1995).

Novak and Bode (1992) used percent affinity to the model to assess the status of streams according to four categories of impairment. Shifts in dominance in the macroinvertebrate community from less tolerant groups to more tolerant groups cause a decrease in percent affinity to the model and suggest impaired conditions at a site. The authors caution, however, that the reasons for deviation from the model community need to be understood; high contributions by an intolerant group may also result in low percent affinity and spuriously suggest impaired conditions. Low species diversity is characteristic of some cold headwater streams, as well as polluted streams. Therefore, if one looks at species diversity, pristine and polluted streams may superficially resemble one another (Hilsenhoff 1977). Examples of this are seen in our data, with site 4 and site 29 having low percent affinities to the Oak Ridges Moraine model, the communities at these sites being over-represented by Ephemeroptera and Plecoptera respectively. At these sites the water was very cold and of all sites these had the lowest numbers of taxa, and also had relatively low numbers of individuals collected. Based on the biotic index scores, however, the water quality at these two sites was excellent. Di Maio (1993) reported a significant positive correlation ($r=0.51$, $p<0.01$) between the number of taxa collected at our Oak Ridges Moraine sites and water temperature, although cautioning that the single-point-in-time temperature readings may be misleading. Gartner Lee Limited (1995) recorded air

temperature and the water temperatures of two headwater tributaries of the Uxbridge Brook continuously from late August to mid-September of 1995. The extent of diurnal water temperature fluctuations varied between the two tributaries - the one with a high proportion of groundwater input had very stable water temperatures (within 1-2°C) despite broad fluctuations in air temperature, whereas the other was more affected by changes in air temperature, with water temperatures fluctuating as much as 4.5°C diurnally.

Further sampling of Oak Ridges Moraine sites in various impact categories would be required to refine the reference model, and to formulate proposed impact categories and associated percent affinity scores. For the time being, the Oak Ridges Moraine model may prove useful as a quick reference tool for the initial screening of sites, given that the requisite community composition information can be readily determined, in most cases even in the field.

The benthic macroinvertebrate communities of two sites in the Duffin Creek drainage basin (site 3 and site 8) were sampled by the senior author ten years ago (MTRCA 1984). A qualitative comparison of these data with the results of the present study reveals similar macroinvertebrate assemblages and physico-chemical conditions. This observation provides at least some anecdotal evidence that, in the absence of disturbance, these headwater streams are quite stable.

In conclusion, the results of this survey indicate that, at most sites sampled, water quality was much better than available surface water quality standards established for the protection of aquatic life and the prevention of nuisance plant growth (MOEE 1994a). All of the streams supported diverse assemblages of benthic macroinvertebrates that included many taxa considered intolerant of pollution (Table 4, Hilsenhoff 1987, Plafkin *et al.* 1989). Water chemistry, physical habitat conditions, and benthic communities varied across sites on the Moraine, however, at two sites for which historical data are available, there appear to have been few changes with time. We recommend that management strategies for the Oak Ridges Moraine explicitly recognize the sensitivity, individuality, and stability of the biological communities of these headwater streams.

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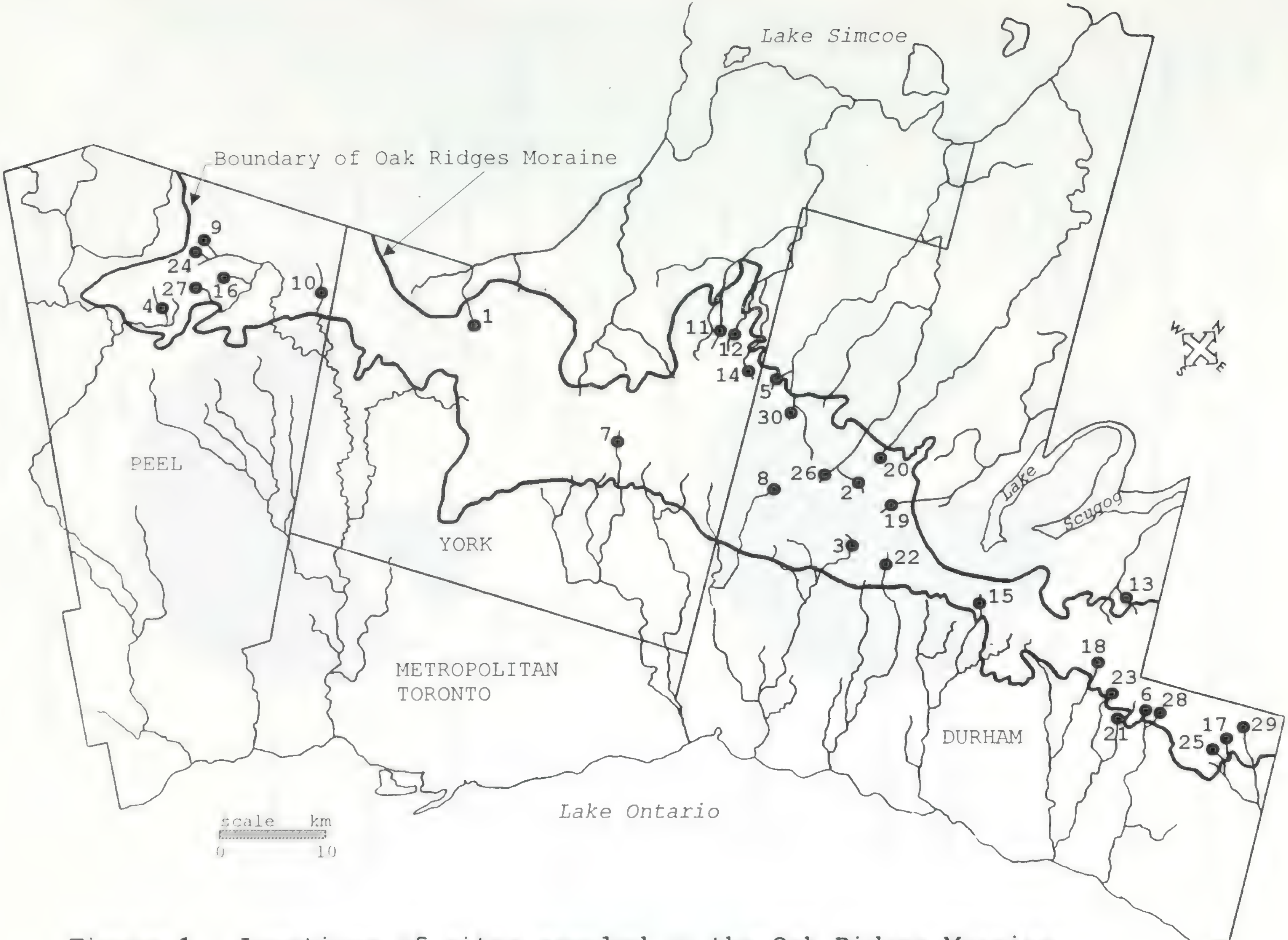

Figure 1. Locations of sites sampled on the Oak Ridges Moraine. See Table 2 for key to site numbers.

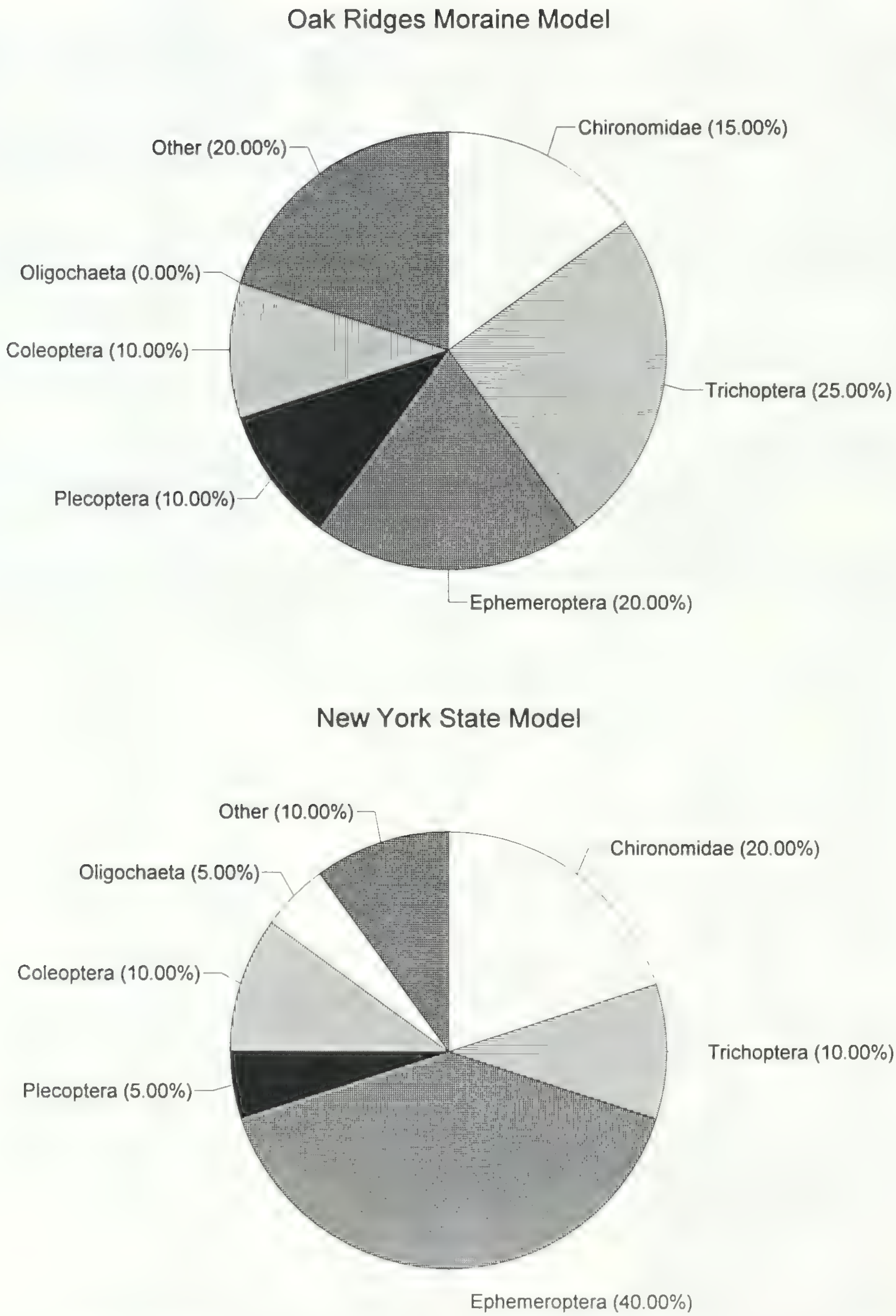

Figure 2. Models of benthic macroinvertebrate community composition.

Table 1. Headwater streams of the Oak Ridges Moraine (from Intera Kenting 1990).

Streams Flowing South to Lake Ontario			
	Peel Region		
		Silver Creek	(Credit River)
		Little Credit River	(Credit River)
		Lindsay Creek	(West Branch Humber River)
		Centreville Creek	(Humber River)
		Humber River	
		Cold Creek	(Humber River)
	York Region		
		East Humber River	
		Rouge River	
		Bruce Creek	(Rouge River)
		Little Rouge Creek	
		West Duffin Creek	
	Durham Region		
		East Duffin Creek	
		Lynde Creek	
		Oshawa Creek	
		East Oshawa Creek	
		Bowmanville Creek	
		Soper Creek	
		Wilmot Creek	
		Ganaraska River	
		Mackie Creek	(Soper Creek)
Streams Flowing North to Lake Simcoe			
	Peel Region		
		Schomberg River	
	York Region		
		Schomberg River	
		Holland River	
		Bogart Creek	(East Holland River)
		Black River	
		Mount Albert Creek	(Black River)
		Vivian Creek	(Black River)
	Durham Region		
		Pefferlaw Brook	
		Uxbridge Brook	
		Beaverton River	
Streams Flowing North to Lake Scugog			
	Durham Region		
		Nonquon River	
		Eastcross Creek	

Table 2. Headwater streams sampled on the Oak Ridges Moraine.

Site Number	Stream Name	Latitude	Longitude	Elevation (m A.S.L.)	Distance from source (km)	Gradient (m/km)	Sampling Date
1	Holland River	43 58'18"W	79 35'15"N	282	0.7	20	20-May-92
2	Uxbridge Brook	44 05'07"W	79 05'10"N	305	2.8	16	21-May-92
3	East Duffin Creek	44 00'17"W	79 04'06"N	267	2.6	14	26-May-92
4	Little Credit River	43 50'35"W	79 55'15"N	312	4.1	21	28-May-92
5	Pefferlaw Brook	44 06'32"W	79 15'05"N	259	3.8	6	01-Jun-92
6	Wilmot Creek	44 02'40"W	78 39'00"N	312	3.0	16	02-Jun-92
7	Bruce Creek	43 57'07"W	79 22'18"N	259	4.5	9	04-Jun-92
8	West Duffin Creek	44 00'40"W	79 11'08"N	297	4.0	6	08-Jun-92
9	Humber River	43 55'17"W	79 54'40"N	351	2.8	12	09-Jun-92
10	Cold Creek	43 55'42"W	79 45'30"N	251	6.4	3	10-Jun-92
11	Black River	44 06'10"W	79 21'20"N	259	1.6	6	11-Jun-92
12	Mount Albert Creek	44 06'35"W	79 19'52"N	251	2.9	12	11-Jun-92
13	East Cross Creek	44 06'05"W	78 45'58"N	282	3.7	20	15-Jun-92
14	Vivian Creek	44 04'41"W	79 17'49"N	297	0.7	15	16-Jun-92
15	East Oshawa Creek	44 00'59"W	78 52'56"N	236	0.9	25	18-Jun-92*
16	Centreville Creek	43 54'52"W	79 51'50"N	325	3.7	20	22-Jun-92
17	Ganaraska River	44 02'43"W	78 32'55"N	221	0.7	20	23-Jun-92
18	Bowmanville Creek	44 02'43"W	7843'35"N	274	0.1	53	29-Jun-92
19	Nonquon River	44 03'24"W	79 02'00"N	274	3.2	5	30-Jun-92
20	Beaverton River	44 05'46"W	79 04'35"N	305	0.4	40	02-Jul-92
21	Soper Creek	44 01'01"W	78 41'10"N	213	3.0	27	08-Jul-92
22	Lynde Creek	44 00'53"W	79 01'28"N	282	3.6	15	16-Jul-92
23	Mackie Creek	44 01'40"W	78 42'42"N	251	1.1	27	22-Jul-92
24	Humber River #2	43 55'54"W	79 54'09"N	319	1.8	14	24-Jul-92
25	Ganaraska River #2	44 02'29"W	78 32'39"N	221	0.0	64	27-Jul-92
26	Uxbridge Brook #2	44 04'44"W	79 06'01"N	305	0.4	12	28-Jul-92
27	Centreville Creek #2	43 52'59"W	79 53'35"N	320	3.0	20	05-Aug-92
28	Wilmot Creek #2	44 02'06"W	78 38'29"N	259	0.8	27	06-Aug-92
29	Ganaraska River #3	44 03'39"W	78 32'36"N	267	0.4	53	10-Aug-92
30	Pefferlaw Brook #2	44 04'50"W	79 12'56"N	282	0.7	10	11-Aug-92

* Field measurements and benthic collection June18, chemistry re-sampled July 8 due to laboratory error with original samples.

Table 3. Water chemistry results for sites sampled on the Oak Ridges Moraine. Chemical concentrations are means of 3 samples.

SITE NUMBER	AIR TEMP (C)	WATER TEMP(C)	D.O. mg/l	DISCHARGE L/s	COND umho/cm	HARD mg/L	ALKT mg/L	pH	TURB ftu	Ca mg/L	Mg mg/L	Na mg/L	K mg/L
1		15	7.1	1	552	235	201	8.2	2.9	75.5	11.4	25.3	0.64
2	26	15	9.3	24	532	244	218	8.3	7.5	77.7	12.2	9.7	1.30
3	12	12	10.0	1	358	191	172	8.5	2.1	51.9	14.8	2.9	0.90
4	16	10	11.0	40	444	247	209	8.3	14.3	70.8	16.9	3.6	1.05
5	21	13	11.1	129	439	229	193	8.3	1.7	74.3	10.5	5.8	0.90
6	23	12	11.1	103	378	195	178	8.3	2.7	60.1	11.0	2.0	0.93
8	17	17	8.6	122	416	214	178	8.3	3.1	62.8	13.9	4.7	1.23
9	19	17	8.2	28	465	227	173	8.2	9.8	61.0	18.1	9.3	1.23
11	24	13	7.8	8	430	234	201	8.1	4.3	73.9	12.1	3.0	0.80
12	27	11	10.0	66	425	222	184	8.3	1.5	66.7	13.4	4.7	1.02
13	19	13	11.4	50	455	240	196	8.2	1.2	76.8	11.6	3.1	0.82
14	21	17	9.6	38	399	200	150	8.3	1.1	63.8	9.8	4.2	0.54
15	23	17	8.6	5	394	209	188	8.4	3.5	62.4	13.0	3.4	1.02
16	18	12	9.5	10	493	263	236	8.4	1.2	73.5	19.3	4.6	1.20
17	18	14	9.5	8	364	191	185	8.4	1.0	57.3	11.5	2.8	0.69
18	26	12	8.4	6	374	200	179	8.1	14.5	64.2	9.7	4.2	0.49
19	14	19	8.1	6	377	205	180	8.3	1.8	65.7	10.0	2.8	0.46
20	22	13	9.8	9	438	231	182	8.1	2.4	72.4	12.2	3.0	0.68
21	18	11	9.4	43	465	256	235	8.4	10.8	75.5	16.4	4.4	1.09
22	24	21	8.2	41	364	184	135	8.3	6.2	47.3	11.2	12.4	0.84
23	18	12	11.0	19	395	240	182	8.4	1.2	64.0	12.6	2.4	0.91
24	17	16	9.0	4	519	250	206	8.4	2.6	74.4	15.5	15.1	1.23
25	19	19	8.1	8	262	136	125	8.3	4.9	39.4	9.1	1.8	1.29
26	24	16	8.1	5	341	179	160	8.2	1.3	55.7	9.7	3.1	0.66
27	21	14	8.8	17	447	250	218	8.4	2.1	74.1	15.9	3.7	0.96
28	24	11	10.4	44	454	219	179	8.3	0.8	69.1	11.2	11.5	0.92
29	20	9	10.9	11	353	190	176	8.2	1.3	59.1	10.2	2.1	0.75
30	20	18	8.1	5	307	159	147	8.2	1.6	50.2	8.1	2.8	0.53
Summary													
n	27	28	28	28	28	28	28	28	28	28	28	28	28
minimum	12	9	7.1	1	262	136	125	8.1	0.8	39.4	8.1	1.8	0.46
25th percentile	18	12	8.2	6	372	194	175	8.2	1.3	59.8	10.4	2.9	0.69
median	20	13	9.4	14	420	220	182	8.3	2.3	65.0	11.9	3.6	0.91
mean	20	14	9.3	30	416	216	184	8.3	3.9	65.0	12.5	5.7	0.90
75th percentile	23	17	10.1	41	454	240	201	8.4	4.5	73.9	14.1	5.0	1.06
maximum	27	21	11.4	129	552	263	236	8.5	14.5	77.7	19.3	25.3	1.30

Abbreviations TEMP=temperature, D O =dissolved oxygen, COND=conductivity, HARD=hardness, ALKT=alkalinity, TURB=turbidity, ftu=Formazin turbidity units, Ca=calcium, Mg=magnesium, Na=sodium, K=potassium, Cl=chloride, SO4=sulphate, P=total phosphorus, PO4=filtered reactive phosphate, TKN=total Kjeldahl nitrogen, NH3=ammonia nitrogen, NO3=nitrate nitrogen, NO2=nitrite nitrogen, DOC=dissolved organic carbon, DIC=dissolved inorganic carbon

Some samples of phosphorus and nitrogen were identified by the laboratory analyst as having trace amounts or concentrations below the detection limits of (in mg/L) P=0 002, PO4=0 001, NH3=0 002

Table 3. Water chemistry results for sites sampled on the Oak Ridges Moraine. Chemical concentrations are means of 3 samples.

SITE NUMBER	Cl mg/L	SO4 mg/L	P mg/L	PO4 mg/L	TKN mg/L	NH3 mg/L	NO3 mg/L	NO2 mg/L	DOC mg/L	DIC mg/L
1	47.6	17.4	0.009	0.0010	0.27	0.002	0.015	0.005	4.4	50.0
2	24.2	20.8	0.012	0.0010	0.24	0.002	2.873	0.010	1.4	53.8
3	2.8	21.1	0.007	0.0010	0.15	0.005	0.405	0.006	1.2	40.9
4	7.6	27.2	0.002	0.0010	0.08	0.002	0.405	0.002	1.1	51.3
5	12.3	23.4	0.013	0.0012	0.24	0.002	0.758	0.008	2.4	47.5
6	4.0	19.3	0.002	0.0010	0.04	0.002	0.533	0.003	0.6	43.0
8	11.0	29.2	0.021	0.0010	0.52	0.065	0.732	0.037	3.2	43.7
9	24.4	30.8	0.027	0.0010	0.33	0.004	2.110	0.013	2.8	41.4
11	2.6	28.3	0.030	0.0072	0.31	0.003	0.082	0.008	4.6	49.4
12	10.1	26.5	0.004	0.0010	0.12	0.002	0.672	0.006	1.3	44.9
13	7.3	22.4	0.007	0.0010	0.23	0.009	4.517	0.013	1.4	43.0
14	13.9	26.5	0.013	0.0005	0.39	0.025	3.710	0.027	2.4	35.2
15	3.8	22.5	0.004	0.0013	0.08	0.002	1.247	0.003	1.6	50.1
16	7.5	34.1	0.025	0.0128	0.21	0.002	0.158	0.008	2.3	53.9
17	2.4	15.0	0.009	0.0010	0.14	0.002	0.022	0.004	1.8	43.7
18	5.4	16.8	0.075	0.0017	0.38	0.002	0.535	0.002	0.7	42.3
19	6.0	18.4	0.014	0.0010	0.28	0.007	0.010	0.003	3.4	42.1
20	10.8	24.5	0.007	0.0010	0.36	0.035	4.030	0.026	1.7	42.3
21	4.4	23.6	0.054	0.0113	0.31	0.002	0.502	0.006	0.8	43.3
22	23.9	19.8	0.025	0.0010	0.38	0.002	0.023	0.002	3.3	31.1
23	6.3	20.2	0.007	0.0010	0.14	0.003	1.703	0.006	0.9	40.7
24	32.4	24.9	0.017	0.0010	0.38	0.015	0.615	0.013	4.4	45.7
25	1.5	14.0	0.024	0.0010	0.35	0.007	0.033	0.003	2.8	29.9
26	4.7	17.7	0.010	0.0010	0.17	0.002	0.097	0.005	2.2	38.8
27	6.5	22.0	0.036	0.0223	0.17	0.002	0.322	0.006	1.7	50.3
28	28.3	15.9	0.005	0.0010	0.16	0.002	1.323	0.004	0.9	42.9
29	1.8	14.4	0.004	0.0010	0.05	0.002	0.138	0.001	0.6	42.4
30	3.7	12.0	0.016	0.0010	0.36	0.047	0.088	0.012	3.9	35.2
Summary										
n	28	28	28	28	28	28	28	28	28	28
minimum	1.5	12.0	0.002	0.0005	0.04	0.002	0.010	0.001	0.6	29.9
25th percentile	4.0	17.7	0.007	0.0010	0.15	0.002	0.095	0.003	1.1	41.3
median	6.9	21.5	0.013	0.0010	0.24	0.002	0.518	0.006	1.8	43.0
mean	11.3	21.7	0.017	0.0028	0.24	0.009	0.988	0.009	2.1	43.5
75th percentile	12.7	25.3	0.024	0.0010	0.35	0.007	1.266	0.010	2.9	48.0
maximum	47.6	34.1	0.075	0.0223	0.52	0.065	4.517	0.037	4.6	53.9

Abbreviations TEMP=temperature, D O.=dissolved oxygen, COND=conductivity, HARD=hardness, ALKT=alkalinity, TURB=turbidity, ftu=Formazin turbidity units, Ca=calcium, Mg=magnesium, Na=sodium, K=potassium, Cl=chloride, SO4=sulphate, P=total phosphorus, PO4=filtered reactive phosphate, TKN=total Kjeldahl nitrogen, NH3=ammonia nitrogen, NO3=nitrate nitrogen, NO2=nitrite nitrogen, DOC=dissolved organic carbon, DIC=dissolved inorganic carbon.

Some samples of phosphorus and nitrogen were identified by the laboratory analyst as having trace amounts or concentrations below the detection limits of (in mg/L) P=0.002, PO4=0.001, NH3=0.002.

TABLE 4. Numbers of benthic macroinvertebrates collected from sites on the Oak Ridges Moraine.

Taxa	Biotic Index Value	Site Number 1	2	3	4	5	6	8	9	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Sum	#Sites
ANISOPTERA																															
Aeshnidae	3																														
Boyena	2							1					8								1		1	4	1					16	6
Gomphidae	1																														
Hagenius	1																	2												2	1
Gomphus	5																							1	1				2	4	3
Cordulegastridae	3																														
Cordulegaster	3					4								1	4	9		4	2		2		9	6	1	1			5	48	12
ZYGOPTERA																															
Calopterygidae	5																														
Calopteryx	5												4										2						1	7	3
COLEOPTERA																															
Dytiscidae	5																														
Hydacticus	5	1																	3											4	2
Agabus	5																1	1	1						2					5	4
Hydroporus	5		1																						1					2	2
Dryopidae	5																														
Helichus	5	3	3				1			11		1			6			2							1		1	1		30	10
Elmidae	4																														
Stenelmis	5	2						81	10							16		28			13		32	17	1				12	212	10
Optioservus	4	25	1	2	2	2		163	22	19		9	7	14	4	44	3	12	1		32	2	21	14	1				15	415	22
Macronychus	4								3												5									8	2
Promoresia	4												3										1						3	7	3
Hydrophilidae	5																														
Crenitis	5		1																											1	1
Hydrobius	5																						1							1	1
Haliplidae	5																														
Haliplus	5												1																	1	1
Psephenidae	4																														
Psephenus	4																	49					1	1						51	3
MEGALOPTERA																															
Sialidae	4																														
Sialis	4	1			1								2	2	1					1										8	6
Corydalidae	0																														
Nigronia	0							9		1			1					10			1		4							26	6
HEMIPTERA																															
Gerridae																															
Gerris		1												1															1	3	3
Rheumatobates																											1			1	1
Veliidae																															
Microvelia		4												1					1					3						9	4
Rhagovelia																		6			1		1	1	1				2	12	6
Hebridae																															
Merragata																1														1	1
PLECOPTERA																															
Nemouridae	2																														
Amphinemura	3	61	11	1		3	5		3	5	3		1	22			7		13	3		9					1	44		192	16
Nemoura	1	1	56														4													61	3

TABLE 4. Numbers of benthic macroinvertebrates collected from sites on the Oak Ridges Moraine.

Taxa	Biotic Index Value	Site Number																												Sum	#Sites
		1	2	3	4	5	6	8	9	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
Perlodidae	2																														
Clioperla	1	5																												5	1
Isoperla	2				2		1								1							4			1		14			23	6
Leuctridae	0																														
Leuctra	0		9								2			3	1		3		1	6		1				1		14		41	10
Chloroperlidae	1																														
Haploperla	1		1				1					3					6			8		5				1	7			32	8
Perlidae	1																														
Agnetina	2			7												5								1						13	3
Paragnetina	1			4					1																					5	2
EPHEMEROPTERA																															
Baetidae	4																														
Baetis	4		22	11	80	6	73	19	12	15	36	88		122	50	10	6	13	24	58	3	69	3	32	58	25	23	1	1	860	26
Heptageniidae	4																														
Epeorus	0			39	17							1																		57	3
Stenonema	3								2	1								1			1		6							11	5
Stenacron	7																	1					1			3				5	3
Leptophlebiidae	2																														
Paraleptophlebia	1			8		25	5	1	6			7		40	20	2		6		1	18	1	3							143	14
Ephemerellidae	1																														
Ephemerella	1			2	3	7	1										1									2				16	6
Drunella	0			16																11		6								33	3
Attenella	1																										2			2	1
Oligoneuridae	2																														
Isonychia	2																				1									1	1
TRICHOPTERA																															
Hydropsychidae	4																														
Hydropsyche	4																														
betteni	6	2						29	4				2			20		3						1	5				24	90	9
slossonae	4					6		26					1	6	1	24				1									2	67	8
sparna	6			5		3		22	6				2	3		13		29	1	2				4	2		1		1	94	14
Diplectrona	0	11								1				17	21						1			4	1					56	7
Parapsyche	0		5				20				6	1					1		1	1		27				10	10	4		86	11
Cheumatopsyche	5							59	11				3	1		1		10			5		39			1			20	150	10
Rhyacophilidae	0																														
Rhyacophila	0	7	27		2		12	6		1	6	14		5	3	1	11		2	5		4			5		14		1	126	18
Uenoidae	3																														
Neophylax	3	22	3	11	2	16	19	1	5	12	26			5		1	2	1									5			131	15
Limnephilidae	4																														
Limnephilus	3	4	9			13					5	2	3		1										1	3				41	9
Psychoglypha	0					13				2	7	6	2							2				1	3	1				37	9
Pycnopsyche	4					8		1		2			5	14	20						1		1	1		1				54	10
Asynarchus	6															1														1	1
Goera	0																							4		3		1		8	3
Philopotamidae	3																														
Wormaldia	0			1																				2			1			4	3
Dolophilodes	0			6								1		1	7	9	90		16	42		12		1	4			35		224	12
Chimarra	4																	42			11		5	1						59	4

TABLE 4. Numbers of benthic macroinvertebrates collected from sites on the Oak Ridges Moraine.

Taxa	Biotic Index Value	Site Number 1	2	3	4	5	6	8	9	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Sum	#Sites
Glossosomatidae	0																														
Glossosoma	0			8			17	4						1						17				3		1	15	3		69	9
Protoptila	1			6												2														8	2
Lepidostomatidae	1																														
Lepidostoma	1					2				5	2	9	17	1	2	1			25	3		1		5	14	1		1		89	15
Helicopsychidae	3																														
Helicopsyche	3							75																						75	1
Hydroptilidae	4																														
Hydroptila	6											13								1										14	2
DIPTERA																															
Simuliidae	6				1		7	1	1	25	1		1	2	10	84	52	1	128	20	4	91	2	22	62	1	1	7	7	531	23
Chironomidae	6																														
Orthocladiinae	5	40	88			17	1	98	28	10	102	26	43	11	17	9	58	5	16	11	9	11	5	3	4	4	7	8	17	648	26
Chironominae	6																														
(Tanytarsini)	6		3	2		4	3			1		3	14		1	1				1	2	2		5		24	8		11	85	16
(Chironomini)	8										2	2	3		3						12		18				6			46	7
Tanypodinae	7					2	1			9	6	8	14	4		5	1	7	2	1	2	2	3	15			3		3	88	18
Tipulidae	3																														
Dicranota	3	2	2				2	1		7	4	8		6	1		14	1	4	3	30	5	7	5	20	6	1	3	6	138	22
Pedicia	6		1																											1	1
Hexatoma	2			3			1	1	1			2		1	8	38	1	3		9		1		3		11		1		84	15
Tipula	4			2		1			1	1			1	1				3		1				1			1		3	16	11
Antocha	3				2	1		35				3								1										42	5
Pseudolimnophila	2								1									6			4									11	3
Limnophila	3											1																		1	1
Oromosia	3																										3	2		5	2
Molophilus	3																											1		1	1
Tabanidae	6																														
Chrysops	6					2			1	1	1		13		1			3					22		6				8	58	10
Empididae	6																														
Chelifera	6		1																								2			3	2
Hemerodromia	6																												1	1	1
Dixidae	1																														
Dixella	1																3							1		1				5	3
Psychodidae	10																														
Pericoma	4																		1											1	1
Athericidae	2																														
Atherix	2												2							1		1	2							6	4
OLIGOCHAETA	8	4	18			6	3		2	2	5	2	1	1	2	2	19		2	2		6	5		5	2	1	1	1	92	22
AMPHIPODA																															
Gammaridae	4																														
Gammarus	4								2	3													5						4	14	4
GASTROPODA	8	1	16					1		1	2	4	1				1		2		2	1		5	9				10	56	14
HYDRACHNIDIA	6				1	1	3				3	31				4	1		6	6	1	7				1	1			66	13
DIPLOPODA			24				2				1	2		1			1		1								1			33	8
TURBELLARIA	6																										1			1	1
HIRUDINEA	6									3													1		5				4	13	4

TABLE 4. Numbers of benthic macroinvertebrates collected from sites on the Oak Ridges Moraine.

Taxa	Biotic Index Value	Site Number 1	2	3	4	5	6	8	9	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Sum	#Sites
ISOPODA																															
Asellidae	8																														
Caecidotea	8	1								2		1								1					15		1			21	6
DECAPODA																															
Cambaridae	6																														
Cambarus	6													3																3	1
Orconectes	6																	1												1	1
BIVALVIA	6												8							1	1			1					2	13	5
Summary																															
number of individuals		198	302	134	113	142	178	634	122	140	220	248	163	290	185	303	286	250	253	220	163	268	201	168	230	104	132	127	167	5941	
taxa richness (Hydropsyche=1)		20	21	18	11	20	20	19	19	24	19	26	25	27	23	22	22	26	22	28	25	22	27	30	26	22	27	16	25		
EPT richness (Hydropsyche=1)		8	9	14	6	10	10	9	8	9	9	11	7	13	11	11	10	8	8	14	8	11	7	12	9	13	11	8	4		
Hilsenhoff Biotic Index		3.46	3.56	1.33	3.21	3.13	2.84	4.24	4.38	4.49	4.17	4.06	4.65	3.22	3.18	4.48	3.16	4.23	4.55	2.59	3.99	3.99	4.90	4.29	4.72	3.64	2.86	1.98	5.26		
25th percentile taxa richness		20																													
25th percentile EPT richness		8																													
75th percentile HBI		4.40																													

Table 5. Relative abundance patterns for major insect orders. Shown is the number of sites at which an order occurred in the specified relative abundance.

	Relative abundance				
Order	Absent (0%)	Rare (0-10%)	Common (10-25%)	Abundant (25-50%)	Dominant (>50%)
Ephemeroptera	2	9	7	7	3
Plecoptera	6	18	2	2	0
Trichoptera	0	1	16	11	0
Coleoptera	3	15	5	5	0
Diptera	0	4	9	12	3

Table 6. Proposed reference values for important indicator parameters. Values are based on summer, dry-weather conditions.

Parameter	Proposed Reference Value
Chemical	
Dissolved Oxygen	>= 90% saturation
Conductivity	<= 450 umho/cm
Chloride	<= 13 mg/L
Total Phosphorus	<= 0.024 mg/L
Total Kjeldahl Nitrogen	<= 0.35 mg/L
Ammonia Nitrogen	<= 0.007 mg/L
Nitrate Nitrogen	<= 1.3 mg/L
Biological	
Benthic taxa richness	>= 20
EPT taxa richness	>= 8
Hilsenhoff's Biotic Index	<= 4.40